Lawrence Livermore National Laboratory

Impacts of autoconversion scheme on simulated cloud properties and aerosol indirect effects

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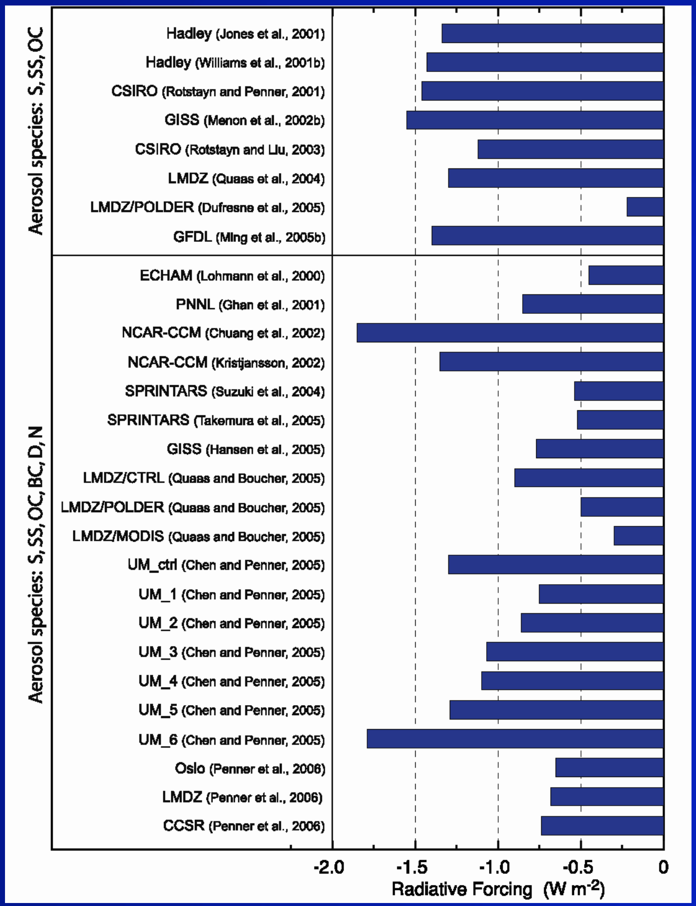
Assessment of aerosol indirect effects is model dependent

Model simulated radiative forcing from the cloud albedo effect (IPCC 2007)



Top panel: results for models that consider a limited number of aerosol species

Bottom panel: results from studies that include a variety of aerosol compositions and mixtures

- Incorporation of more aerosol species and improved treatment of aerosol-cloud interactions allow a best estimate of the cloud albedo effect , However, the uncertainty remains large.

- Every model has its own treatments for aerosols, cloud dynamics and microphysics, as well as aerosol/cloud interactions.

Model intercomparison itself can not identify the source of uncertainties.

- In this study, we use one model, prescribed aerosols, and parameterized aerosol/cloud nucleation to examine the short-range model response to treatments of autoconversion and identify their impacts on the estimation of aerosol 1st and 2nd indirect effects.

Cloud microphysics packges in CAM3.5

- Default RK cloud microphysics scheme does not account for aerosol effects.

Prescribed cloud drop r_{el} in radiation

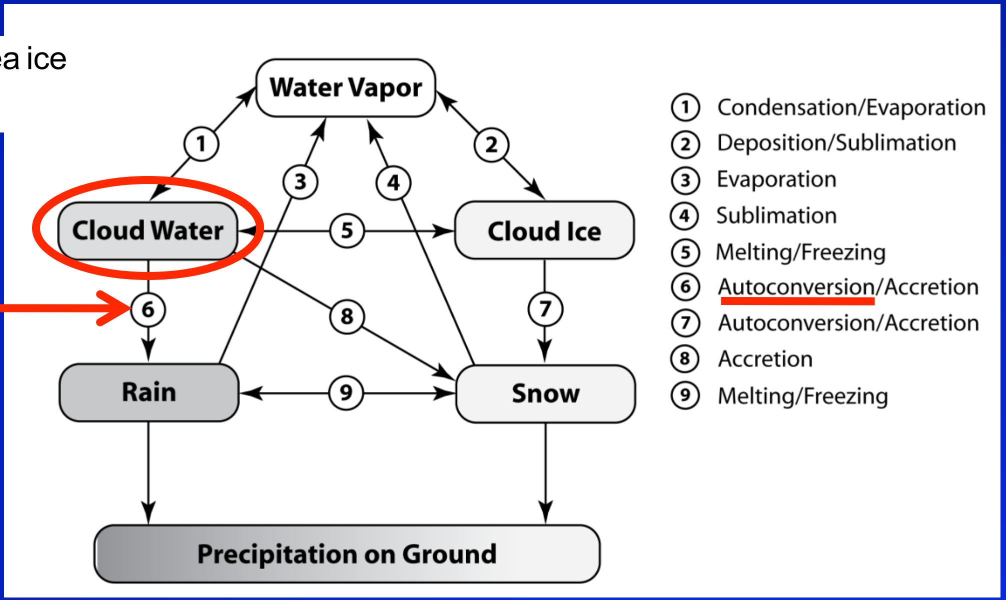
$$r_{el} = \begin{cases} 14\ \mu m & \text{over ocean and sea ice} \\ 8\text{-}14\ \mu m\ \text{(T dependent)} & \text{over land} \end{cases}$$

Prescribed cloud drop number N_d in autoconversion

(A process to initiate raindrops by collisions and coalescence of cloud droplets.)

$$N_d = \begin{cases} 75\ cm^{-3} & \text{over sea ice} \\ 150\ cm^{-3} & \text{over ocean} \\ 400\ cm^{-3} & \text{over land} \end{cases}$$

RK Cloud microphysics scheme



- New MG cloud microphysics scheme accounts for aerosol/cloud interactions and prognostically calculates cloud drop number and mass, but can not isolate cloud albedo and lifetime effects from the total indirect effects.

Modify RK scheme to include aerosol/cloud interactions

- Implement cloud nucleation parameterization to diagnostically derive N_d based on aerosol characteristics (composition, number, and the prescribed size distribution) and updraft velocity

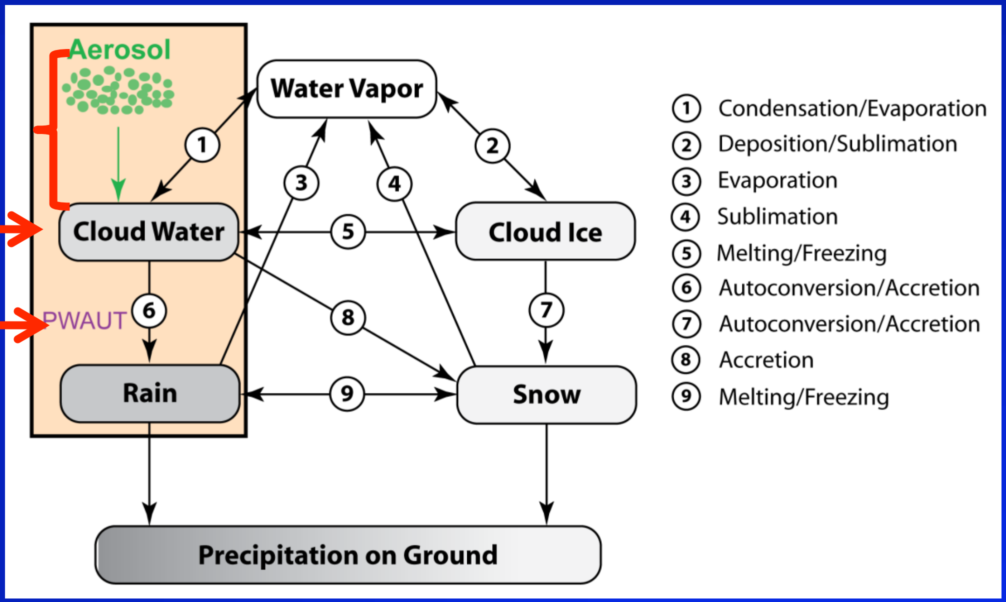
Modified RK Cloud microphysics scheme

Cloud Drop Nucleation

(The process to activate aerosols to form cloud droplets.)

Calculate cloud drop r_{el} in radiation

Apply N_d in autoconversion



- Modified RK scheme is useful for sensitivity experiments to identify aerosol 1st and 2nd indirect effects although it neglects the impacts of other processes (i.e., collision, entrainment, advection, …) on N_d.

Autoconversion schemes evaluated in this study

Two types of autoconversion schemes

- Model-based parameterization from numerical evaluation of stochastic collection equation [*Beheng, Berry, Khairoutdinov-Kogan*]
- Kessler-type parameterization in which autoconversion is treated as a threshold process [*Liu and Daum, Manton and Cotton*]
  - The threshold behavior is represented by a Heaviside function. Autoconversion process is turned on abruptly when a specified variable exceeds its critical value. The selection of critical value is somewhat arbitrary.

Beheng (1994)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = 6\times10^{25}\, n^{-1.7}\, \rho_a^{3.7}\, N_c^{-3.3}\, q_l^{4.7}$$

Berry (1968)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = \frac{\rho_a\, q_l^2}{1.2\times10^{-4} + \dfrac{1.596\times10^{-12}\, N_c}{D_o\, \rho_a\, q_l}}$$

Khairoutdinov-Kogan (2000, CAM3 MG)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = 1350\, q_l^{2.47}\, N_c^{-1.79}$$

Liu-Daum (2004)

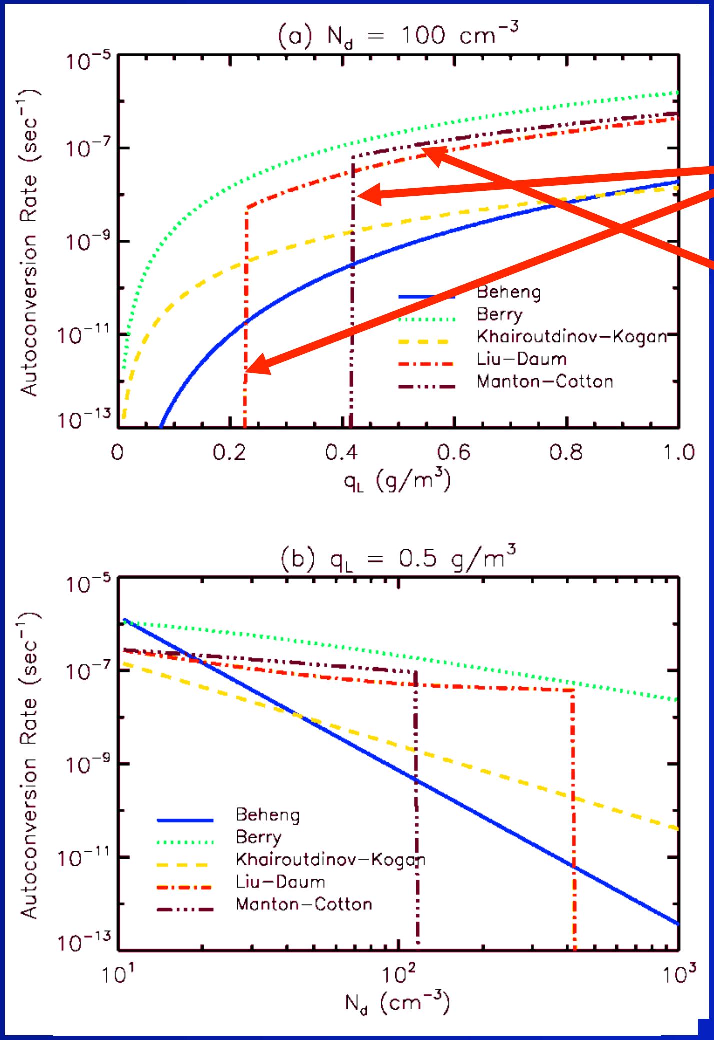
$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = \kappa_2 \left(\frac{3\,\rho_a}{4\,\pi\,\rho_w}\right)^2 \beta_6^6\, \frac{q_l^3}{N_c}\, \underline{\mathrm{H}(R_6 - R_{6c})}$$

Manton-Cotton (1977, CAM3 Default)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = C_{l,aut}\, q_l^2\, \frac{\rho_a}{\rho_w} \left(\frac{q_l\, \rho_a}{\rho_w\, N_c}\right)^{1/3} \underline{\mathrm{H}(r_{3l} - r_{3lc})}$$

Autoconversion rate varies significantly with N_d and q_L

Autoconversion rates from different schemes for typical ranges of N_d and q_l in boundary layer clouds



Following the treatment in CAM

- A modified Heaviside function is applied to **Kessler-type schemes** for a smooth transition near the threshold value.
- Adjust MC scheme by the range of (0.1, 1) based on the local rain flux

The predicted rates differ by several orders of magnitude and the differences are more pronounced for higher values of N_d.

- Autoconversion rates increase with q_L but decrease with N_d.
- In general, BER predicts the largest rate, followed by MC, LD, KK, and BEH.
- BEH is excessively sensitive to N_d and q_L.

Sensitivity of cloud properties to autoconversion scheme under CAPT during May 2003 Aerosol IOP

Mean values over SGP during Aerosol IOP

	Autoconversion Scheme prescribed r_{el} in radiation prescribed N_d in autoconversion				
	BEH	BER	KK	LD	MC
LWP (g m^{-2})	65.37	32.20	70.77	42.61	37.85
Low Cloud (%)	7.73	9.66	7.74	8.99	8.93
Med Cloud (%)	7.76	8.13	7.95	7.90	8.09
High Cloud (%)	19.78	19.47	19.42	19.39	19.68
PPT (mm day^{-1})	2.67	2.68	2.71	2.61	2.64
SWCF (Wm^{-2})	-24.74	-26.31	-24.50	-26.21	-26.42
LWCF (Wm^{-2})	17.03	16.97	17.18	16.91	16.72
Net TOA SW (Wm^{-2})	357.28	355.66	357.52	355.78	355.56

- BEH and KK predict a very high LWP but a smaller low cloud fraction than BER, LD, and MC.

Higher autoconversion rates from BER, LD, and MC
→ Higher rain mixing ratio, lower LWP

Evaporation of rain drops
→ Increase RH
→ Higher cloud fraction

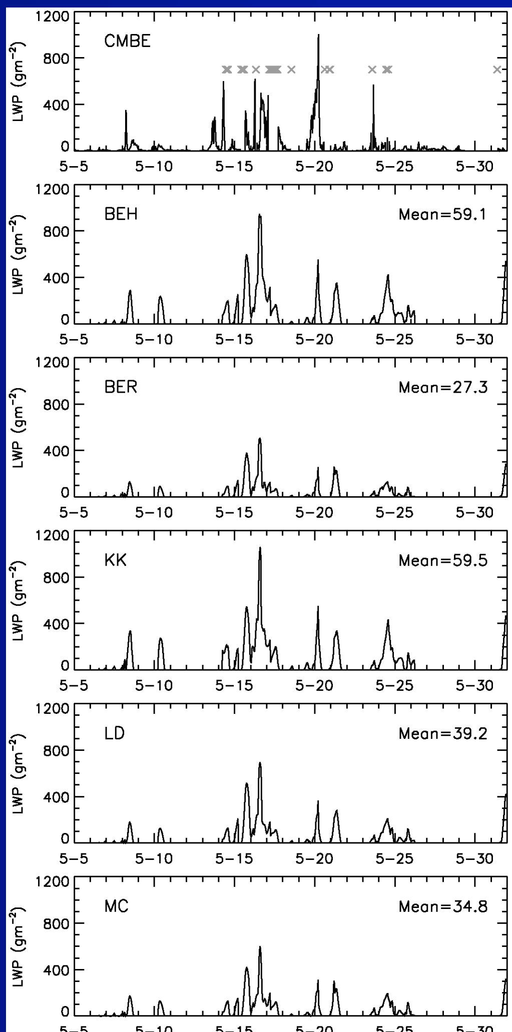
- The smaller low cloud fractions from BEH and KK corresponding to the low autoconversion rate seem to overwhelm the impact of LWP on SWCF.

  BEH and KK yield a smaller magnitude of SWCF and a larger net TOA SW.

- Max. difference in the average of SWCF during IOP is up to 1.86 Wm^{-2} .

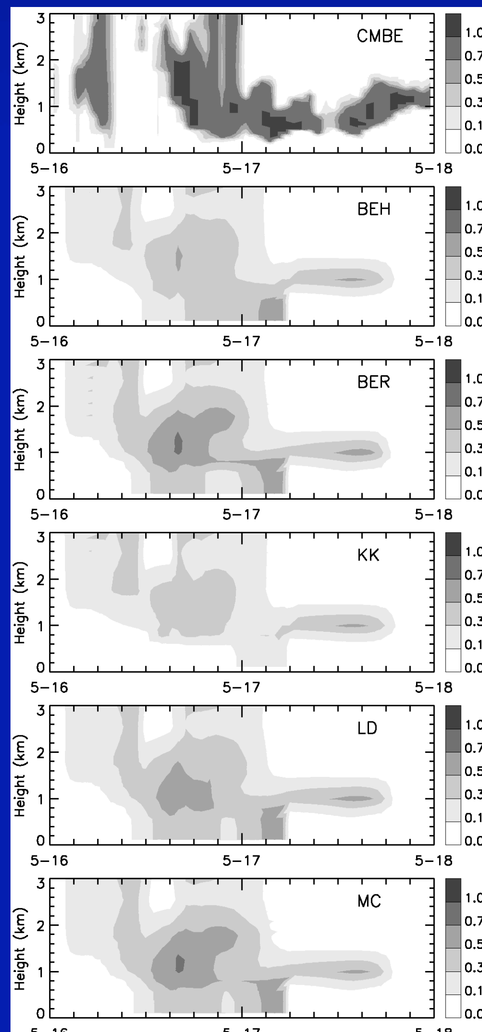
Comparison of simulations to ARM data over SGP (with r_{el} and N_d from Abdul-Razzak nucleation parameterization)

Hourly LWP



Data based on MWRRET VAP

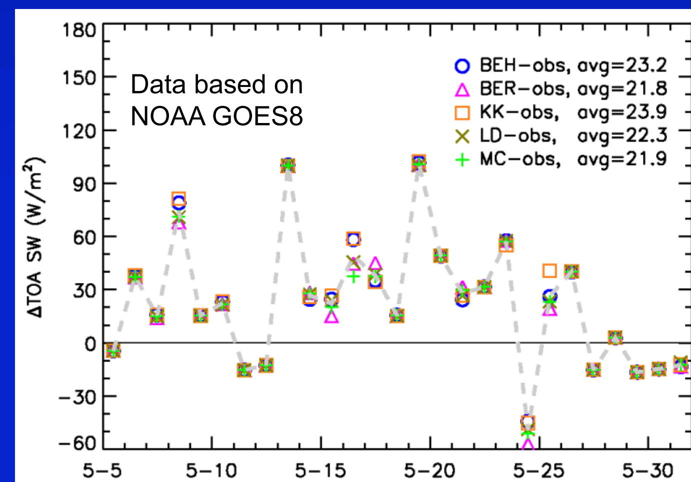
Cloud fraction on May 16-17



Data based on ARSCL VAP

- Simulations miss the cloud occurrence on May 13 and seem to delay the cloud development on May 23 by one day.
- Simulated cloud fractions from different schemes vary significantly in the convection core.

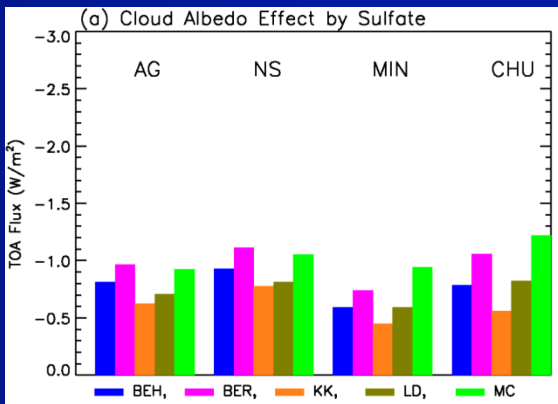
Daily deviation of net TOA SW from data

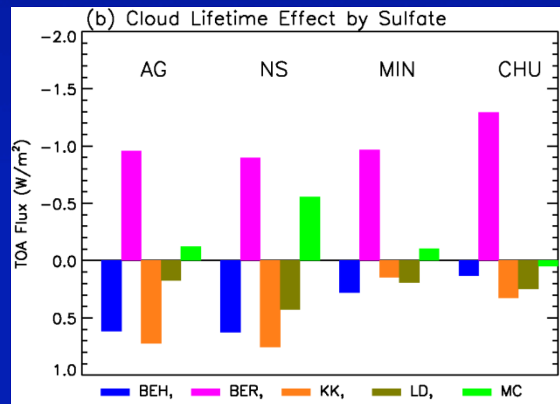


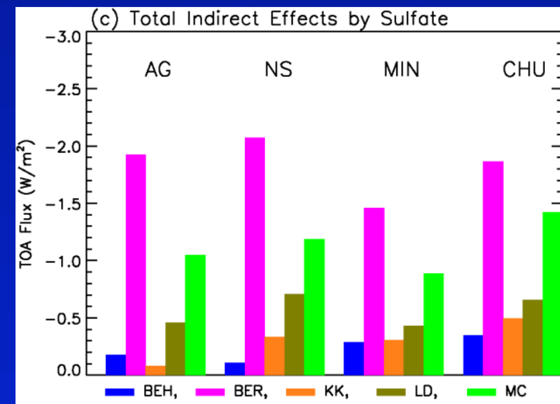
- Larger deviations are correlated with the occurrence of cloud events.
- CAM3 in general underestimates the magnitude of cloud forcing over SGP regardless the use of autoconversion scheme.

Sensitivity of (total) sulfate indirect effects over SGP during Aerosol IOP

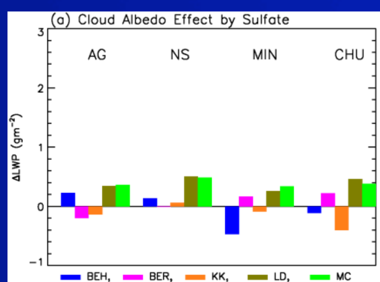
- Changes of net TOA SW from (a) cloud albedo, (b) cloud lifetime and (c) total indirect effects

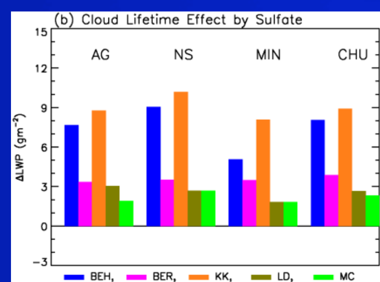




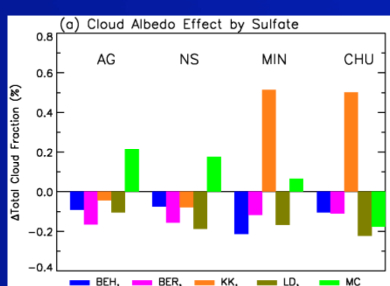


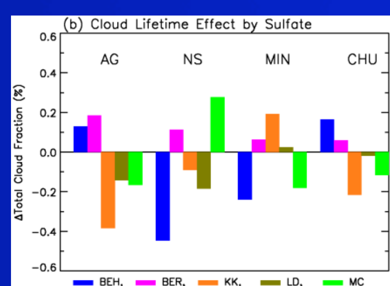
ΔLWP





ΔTotal CF

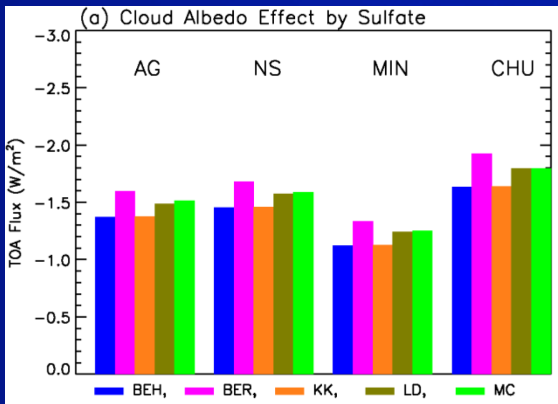


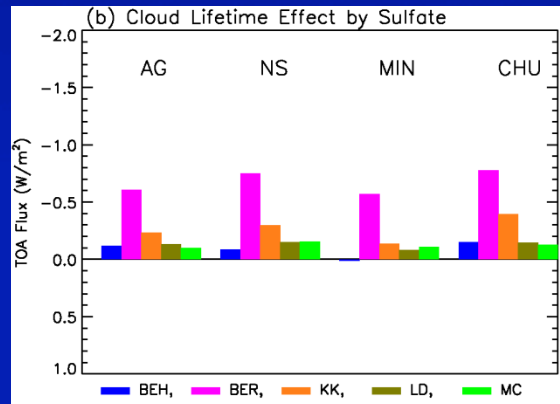


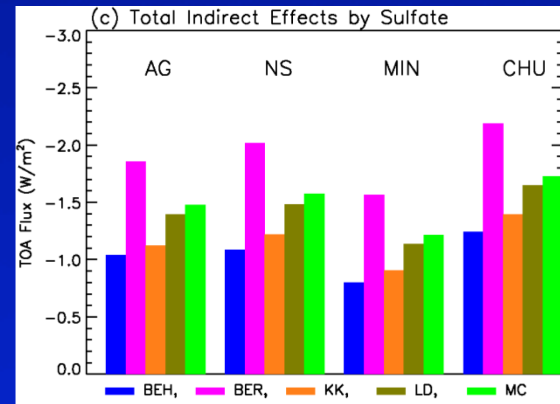
- Cloud albedo effect by sulfate varies in the range of -0.5 and -1.2 W/m^2
- Cloud lifetime effect by sulfate is much more sensitive to autoconversion scheme than cloud nucleation parameterization.
- Response of cloud properties to the 1st aerosol indirect effect varies in sign and magnitude.
- Magnitude of the 2nd aerosol indirect effect is determined by two competing factors, interact nonlinearly: an increase of LWP and the variation of cloud fraction.

Global sensitivity of sulfate indirect effects during Aerosol IOP

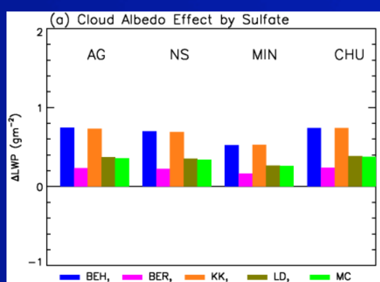
- Changes of net TOA SW from (a) cloud albedo, (b) cloud lifetime and (c) total indirect effects

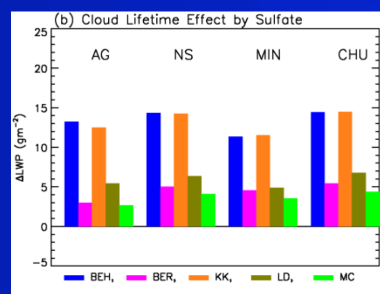




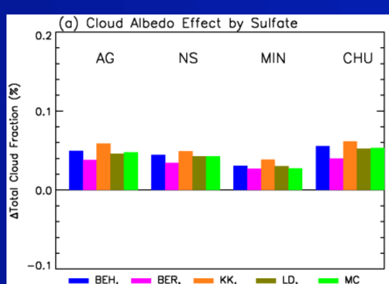


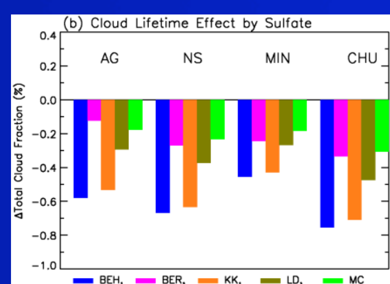
- ΔLWP





- ΔTotal CF





- Global averages smooth out the local variations.
- On the global average, both LWP and total CF increase with aerosol sulfate from cloud albedo effect.
- LWP increases with sulfate but the total CF reduces from the cloud lifetime effect.
- Results are for May 2003 Aerosol IOP . Other season may present different relationship.

Summary

- CAM3 in general underestimates the magnitude of cloud forcing over SGP during May 2003 IOP regardless the use of autoconversion scheme.
- LWP is very sensitive to autoconversion scheme. The corresponding change of cloud fraction plays an important role in the magnitude of radiative forcing from cloud lifetime effect.
- Sensitivity of aerosol indirect effects to autoconversion scheme is temporal and spatial dependent. Findings over measuring sites help to understand the foundational physics. More aerosol IOPs to further explore the source of uncertainties is needed.

- Future work:

  Apply CAM3/4 with interactive aerosols and sectional aerosol microphysics to examine the sensitivity of IE(= dlnR_e / dlnτ_a) to cloud parameterizations.

  Compare IE with those derived from ARM data at SGP or other available data.